REVIEW: DETERMINING AND OPTIMIZING CHEMICAL APPLICATION RATES AND SPRAY APPLICATION IN DIFFERENT AVOCADO CANOPIES

D. Manktelow and W. May
Applied Research and Technologies Ltd, PO Box 3415, Napier
[2]Spray Tec Consultants Ltd, PO Box 9227, Tauranga
Corresponding author: davidm@agribusiness.ac.nz

ABSTRACT

Chemical registration field trials aim to achieve even target coverage and dosing by using high volume sprays that achieve a high level of target wetting with some runoff in the outer canopy ("the point of runoff"). Chemical rates applied in these tests can then be expressed as a concentration to mix per 100 litres for "dilute" spraying and it is left to the spray applicator to work out the application volumes required to treat canopies of different sizes and densities and how to most efficiently deliver the spray to the target. In practice the volume of spray required to wet different canopies to the point of runoff will vary with the density of the target canopy. It is quite acceptable to deliver equivalent rates of chemical (per tree or per hectare) in application volumes below the point of runoff by using a more concentrated chemical mix. Such "concentrate" spray applications usually result in deposits that are 10-20% higher but more variable than those from application of equivalent amounts of chemical in volumes at the point of runoff.

The most practical and relevant system for setting up sprayers to deliver target application volumes to different trees is one in which the sprayer is calibrated to deliver a target output for different canopies on a distance travelled rather than area treated basis. For crops like avocados with variable tree sizes and row spacings, the more traditional approach of calibration to deliver target application volumes per planted hectare can be expected to lead to variations in dose achieved - with all of the associated implications for potential efficacy, spray residues and variations in the efficiency and economics of agrichemical use. On the basis of the results from recent spray deposit testing work undertaken on NZ avocado canopies, an Australian system for distance based calibration has been adapted for use with New Zealand avocado canopies. Tables giving recommended spray delivery volumes per 100 metres of sprayed row have been prepared for different sized canopies, along with a table specifying the required litre per minute sprayer output volumes to deliver these target application volumes at different travel speeds.

Keywords: *tree row volume, coverage, spray target*

INTRODUCTION

The process by which agrichemicals are registered usually starts with laboratory screening for potential efficacy. Candidate chemicals are then taken to small plot field trials (usually using individual tree replicates) based on protocols that have been long established and accepted by the agrichemical industry (Hickey, 1986). Traditionally small plot spray applications are made as high volume ("dilute") sprays using high-pressure, hand held spray guns. All target surfaces are thoroughly wetted to a point where some excess spray liquid just begins to drip to the ground ("the point of runoff"). Each tree or vine is treated individually in such trials using the drip point as a visible gauge for equivalent dosage, so it is expected that all parts of the plant receive an even chemical dose. It is also assumed that all plant targets in these types of field tests can be treated equally regardless of differences in size, shape or growth stage. This approach ensures a high level of plant surface coverage and means that the level of control achieved in any treatment is directly related to the concentration of chemical applied. This type of testing provides the basis for the dilute chemical mixing rates (chemical rate per 100 litres of dilute spray mix) that appear on all chemical labels for fruit crops in New Zealand.

Spraying to the point of runoff aims to eliminate dosage variations between treatments or experiments. However, there will always be some variations in the chemical doses achieved in small plot field trials. For example, there are variations between spray applicators in their perception of the wetting required to reach the point of runoff. There are also variations in how much chemical can be loaded onto plant surfaces when different droplet sizes or wetting agents are used. It is worth noting that this has implications for the potential efficiency of different spray application methods in a commercial field situation. For example, it is generally accepted that the application of chemicals in volumes below the point of runoff will result in deposits that are 10-20% higher, but more variable, than those from application of equivalent amounts of chemical per tree or per hectare in volumes at the point of runoff losses (Manktelow, 1998).

In practice actual spray deposits and hence potential variations in deposits between treatments and tests from chemical registration tests are seldom quantified. The focus of chemical testing work is quite appropriately on pest or disease control outcomes and chemical residues at harvest. The chemical testing protocols used to develop label rates have served well to identify potentially useful agrichemicals and to define application rates that can be expected to work in commercial practice. The key assumption behind the resulting chemical label rate recommendations is the use of high volume sprays that achieve a high level of target wetting with some runoff in the outer canopy. It is left to the spray applicator to work out the application volumes required to treat different canopies and how to most efficiently deliver the spray to the target.

An important part of achieving consistency in interpretation of agrichemical rates is to make sure that everyone involved in the industry uses a consistent language with the same interpretations of different terms. The following are some definitions of different spraying terminology:

High volume or "dilute" spraying

The application of agrichemicals using the rate per 100 litres found on chemical labels. The application volume in this case should result in some dripping seen from the outer canopy, with the majority of the inner canopy wetted by spray droplets (about 50% of total surface area evenly wetted with droplets). The volumes needed to achieve this will vary with canopy size and density, to achieve coverage in the inner part of a dense canopy more volume will be required, and more runoff will be seen in the outer canopy than will be seen in a more open canopy.

Low volume, "concentrate" spraying

Uses the chemical application rate established for dilute spraying and applies this in a lower volume – usually a factor of 2X, 3X or 5X is used. For example, if a particular canopy is sprayed dilute to the point of runoff using a chemical rate of say 100 g/100 litres and a sprayer emission of 90 litres per minute at 3 km/hr, a 3X concentrate spray application will apply 30 litres per minute at 3 km/hr using a chemical rate of 300 g/100 litres. Expressed in terms of chemical application rates per hectare, both dilute and concentrate should be the same although reduced runoff losses from concentrate applications can, in some cases, allow concentrate chemical application rates to be reduced by between 10% and 20%.

Application rate

Ideally refers to the amount of chemical sprayed per 100 litres of spray mix. However application rates are often used to describe the quantity of chemical applied per planted hectare. Rates per hectare are useful in budgets but variations in canopy size and spacings mean that rates per hectare are an extremely unreliable indicator of chemical doses achieved.

Coverage

Refers to the percentage of target surface covered by droplets (%) and may be further described in terms of deposit distribution on the target surface. Usually it is only necessary to determine whether deposits are evenly or unevenly distributed. Uneven distributions as are usually seen in dense areas such as where fruit are clustered are likely to lead to control problems. Coverage is determined by the way the sprayer outputs air and spray liquid interact with the canopy being sprayed and how the spray droplets behave on the surface of the plant (Gaskin and Pathan, 2006).

Dosage

Refers to the amount of chemical deposited per unit area. This is most usefully expressed as micrograms per square centimetre (µg/cm^2) of leaf or fruit surface area. Dosages achieved represent the interaction between application rate, coverage and the canopy being sprayed.

It is important to recognise that both dose and coverage have to be right; good coverage with a sub-lethal dose, or poor coverage with a high dose, can both fail to provide control.

DEFINING CHEMICAL APPLICATION RATES AND SPRAY VOLUMES FOR NEW ZEALAND AVOCADOS

Interpreting current chemical label rates

There were 31 fungicide and insecticide products listed in the 2006 NZ Novachem manual with label rates for spraying avocados. All of these provided a rate or rate range per 100 litres of spray mixture for dilute spray application. Ten products also included recommended rates per treated hectare, with occasional reference to spraying mature trees and four gave minimum recommended application volumes. When all of these alternative rates were converted to a minimum recommended water volume per hectare, the average recommended water volume was close to 2,500 litres per hectare, but ranged from 1,500 to 4,000 litres per hectare. Given these large variations it should be apparent that the label rate per 100 litres is the only consistent guide you have to determining the right amount of chemical to apply to your trees. Twelve of the 31 products listed gave possible ranges in chemical mixing concentrations for the product, with these ranges reflecting application rates needed to control different levels of pest or disease risk. This is useful information that can be used to refine your product rate decisions.

So where does that leave agrichemical users when they try to define the chemical application rates needed for different tree canopies? Application rate requirements are dictated firstly by the ***canopy target*** and should be refined in light of pest or disease risk or pressure. The variables that make up the canopy target can be defined in terms of ***tree size, form* and *density***. Collectively these describe the total surface area of canopy target that needs to be treated, but it is seldom practical to attempt to quantify this.

Defining the spraying target on the basis of canopy volume

All fruit industries face the problems of target application rate definition and the most successful method for free standing tree crops has been to define the volume of spray liquid it takes to cover a given ***volume of crop canopy***. The concept of using canopy volume to determine chemical application rate requirements was developed in the USA as the Tree Row Volume or TRV spraying for apple canopies and has been successfully tested on apples and citrus in New Zealand (Manktelow and Praat,1997; Manktelow, 1998; Manktelow *et al.,* 2004).

The logic behind TRV spraying is simple – think of painting the exterior of a house: the more wall area your house has, the more paint you will need. The larger the floor area of the house the larger the wall area will be. Likewise, the more storey's the house has the larger the wall area will be. The surface texture of the house will also affect the amount of paint needed, with rough stucco textures (read dense canopies in trees) needing far more paint to cover them than smooth cladding (read open canopy in trees). Trees are obviously a little more complicated to "paint" with spray because they have targets (leaves, fruit, buds etc.) distributed throughout a volume of space with some variations in canopy density. However, it is reasonably easy to estimate the required spray application volume based on the volume of space occupied by your tree canopy. This process is outlined later in this document.

Hectare based versus distance travelled application volume targets

A problem with the TRV approach is that it anchors chemical application rate requirements back to application rates per hectare. The use of hectare based rates is far from ideal in avocados. This is because variations in row spacings with tree removals over time can result in very large variations in the canopy volume present per hectare on different blocks, despite apparently similar individual tree sizes. In practice most spraying is done using single sided sprayers, with the sprayer operated a constant distance from the canopy that is effectively independent of the row spacing. In this situation it is much better and easier to express tree target application volume requirements in terms of sprayer output volumes per 100 metres of distance travelled.

A "*distance calibration*" approach to spraying has been championed by an Australian researcher Geoff Furness (Furness, 2005). A more complete description of this approach can be found at the following website address:
http://www.sardi.sa.gov.au/pdfserve/hort/products_services/sardi_fan/distcalcroplandsb.pdf

In this approach a spray coverage factor is set for different canopy densities and expressed as an application volume to deliver per 100 metre length of row for each metre of tree height and spread. This approach is excellent in that it becomes very easy to develop tables that specify sprayer outputs required per metre of tree height to deliver target application volumes at different travel speeds. As with any system that attempts to define spray application volume requirements in relation to tree canopy volume, ***the coverage factors selected will define the application volumes recommended.*** Unfortunately the coverage factors recommended by the Australian researchers are currently higher than those identified as appropriate for New Zealand canopies, so use of the Australian coverage factors would lead to use of spray application volumes above currently those proven to be effective in New Zealand. For example, the coverage factors recommended by Furness (2005) for tree crops are 18-28 litres per metre of tree height per 100 metres of travel (single sided spraying) for open and dense canopies respectively. These coverage factors would equate to recommended application volumes of 2600 to 4000 litres per hectare for a five metre tall canopy on a seven metre row spacing. Current industry experience indicates that an NZ canopy of this size would be expected to require between about 2000 and 3000 litres per hectare for effective pest and disease control.

Draft canopy volume application guidelines for New Zealand avocados

The experimental and survey work undertaken as part of the AIC Sustainable Farming Fund project on optimizing spray application practices on NZ avocados has. found that small (<5m tall) and large (>7m tall) trees are easier to evenly spray than medium sized trees (5-7m tall) which tended to have the densest leaf canopy (see Figure 1 for examples of small, medium and large canopies). Observations of blocks in different production regions confirmed that tree spread and height tend to be in direct proportion (*i.e.* canopy spread is a good predictor of tree height) until trees begin to meet to form a continuous canopy (Manktelow *et al.*, 2006; Gaskin and Manktelow, 2006; Gaskin and Pathan, 2006). Further observations have also confirmed that the large variations in tree sizes and spacings that can occur within blocks, such as tree thinning and pruning or replacement of damaged or diseased trees, render the concept of a target hectare of avocados almost meaningless. In practice it has been found that most sprayer operators apply sprays from single sided sprayers which are driven a constant distance from the edge of the tree canopy, unless the sprayer is forced under the canopy where trees have met across rows. This type of spraying pattern lends itself well to the establishment of a distance based spray application methodology and language for the industry.

The following tables and text outline a distance based spray application system for NZ avocados.

Step 1: Identify the sprayer application rate required (in litres per 100 metres of row) for your particular canopy (Table 1).

At this stage you will need to make a decision on how dense the canopy is and what level of wetting and coverage you require. Work on other crops has shown that one litre of dilute spray can effectively cover between 17 and 11 cubic metres of canopy volume to the point of runoff for open to dense canopies, respectively. These estimates of potential coverage based on canopy density are termed *coverage factors.* To fully drench a dense canopy such as citrus (for example, to apply oil sprays to smother pests like scale insects) a lower coverage factor of around 7 cubic metres of canopy volume per litre of spray mix will be required – use of such very low coverage factors is not expected to be required in New Zealand avocados.

In low vigour or open, relatively hollow, avocado trees a coverage factor of between 17 and 14 cubic metres per litre can be expected to apply, while in dense avocado canopies, typically medium sized trees that have a continuous leaf canopy to the trunks, a coverage factor of 14 to 11 cubic metres per litre would be more appropriate (Figure 1).

Note that empty spaces in tree centres or unskirted areas beneath trees that are not occupied by canopy so can be omitted from any tree volume estimates. The spray volume requirements estimated for different canopies in Table 1 account for loss of inner canopy foliage in large trees in excess of about 7 metres in height and spread, as typically seen in current New Zealand 'Hass' canopies. Where canopies lack foliage skirts, the tree height and spread estimate should account for just the foliated height and spread of the trees.

Step 2: Use Table 2 to work out the sprayer output volume required to deliver the target application rate per 100 metres of row length at your desired travel speed.

Check the calculation to be sure that your sprayer pump has the capacity to deliver the required output volume at your desired travel speed while still having output in reserve for tank agitation. Also

Figure 1: Three different tree sizes (3m, 5-6m and 8-9m) showing comparable heights and spread. Pole in photos = 5m tall. Note greater canopy density in the smaller trees, with the medium canopy presenting the most difficult spraying target and hence needing a smaller coverage factor (= higher application volume per cubic metre of canopy) than the more open large canopy.

confirm that the air output from the sprayer will deliver the spray plume into the tops and centres of the trees. If not you will need to slow down.

Step 3: Confirm that your sprayer nozzle arrangement delivers the required spray volume evenly through the tree.

A good rule of thumb for setting up nozzles for spraying avocados is to direct two thirds of sprayer output out of the top third of the effective nozzles into the top third of the tree.

Step 4: Mix and apply using the dilute rate per 100 litres of chemical on the product label.

If you are going to use lower volume concentrate sprays, then select a target litres per 100 metres of row out that matches your concentration factor. For example, to apply a three times concentrate spray in a canopy that requires 90 litres per 100 metres of row as a dilute application volume, then your target application volume would be 30 litres per 100 metres of row, with the chemical mixed in the tank at three times the label rate per 100 litres of dilute spray mix.

Table 1. Spray application volumes required in litres per 100 metres of row length to treat avocado canopies of different sizes and densities.

	Coverage factor[1] Cubic metres of canopy volume covered per litre of dilute spray mix, for open (lhs) to dense (rhs) canopies						
	17	**16**	**15**	**14**	**13**	**12**	**11**
Tree height and spread[2] (m)	**Spray volume required[3] (Litres per 100 metres)**						
3	26	28	30	32	35	38	41
4	47	50	53	57	62	67	73
5	74	78	83	89	96	104	114
6	106	113	120	129	138	150	164
7	144	153	163	175	188	204	223
8 to 12 m	144	153	163	175	188	204	223

[1] *Smaller coverage factors relate to higher spray application volumes, where: 17 relates to very open canopies, 14 relates to typical healthy canopies and 11 relates to dense canopies with few gaps or hollows to aid spray penetration (as often seen with 5-7m tall trees that have a continuous leaf canopy to the trunks).*

[2] *Tree canopy volumes for trees up to 7 metres tall have been estimated on the assumption that tree height and spread are similar and that there is foliage in the entire tree volume. For trees between 8 and 12 metres in height canopies are assumed to have effectively filled the available land area and carry similar leaf and fruit canopy volumes, with the variations in height and spread simply reflecting a different distribution of this potential canopy in space (i.e. larger unfoliated volumes beneath larger trees).*

[3] *The litre per 100 metre application volume requirements assumes that trees will be sprayed from two sides when sprayed in rows, or in the case of large individual trees, that the periphery of the tree will be driven around.*

There is no need at any point in the distance based calibration above to attempt to relate sprayer setup and application volumes to ground area. The focus on spray application is to deliver an effective dose of chemical to the target with sufficiently even coverage to achieve control of the target pest or disease. Establishing a simple sprayer output requirement per distance sprayed for different sized trees is expected to greatly improve the consistency with which dose and coverage are achieved across the New Zealand industry. Avocado plantings frequently have large gaps between trees when blocks are being established or where replants or staghorn pruning has occurred. Turning off the sprayer output in such gaps will minimise both spraying cost and

Table 2. Sprayer outputs required to deliver target litre per 100 metre of row application volumes at different travel speeds.

Target application volume[1] (litres per 100 metres of row)	Travel speed2 (km/hr) Output required from one side of the sprayer[3] (litres per minute)						
	2.0	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**
20	7	8	10	12	13	15	17
25	8	10	13	15	17	19	21
30	10	13	15	18	20	23	25
35	12	15	18	20	23	26	29
40	13	17	20	23	27	30	33
45	15	19	23	26	30	34	38
50	17	21	25	29	33	38	42
55	18	23	28	32	37	41	46
60	20	25	30	35	40	45	50
65	22	27	33	38	43	49	54
70	23	29	35	41	47	53	58
75	25	31	38	44	50	56	63
80	27	33	40	47	53	60	67
85	28	35	43	50	57	64	71
90	30	38	45	53	60	68	75
95	32	40	48	55	63	71	79
100	33	42	50	58	67	75	83
110	37	46	55	64	73	83	92
120	40	50	60	70	80	90	100
130	43	54	65	76	87	98	108
140	47	58	70	82	93	105	117
150	50	63	75	88	100	113	125
160	53	67	80	93	107	120	133
170	57	71	85	99	113	128	142
180	60	75	90	105	120	135	150
190	63	79	95	111	127	143	158
200	67	83	100	117	133	150	167
210	70	88	105	123	140	158	175
220	73	92	110	128	147	165	183
230	77	96	115	134	153	173	192

[1] Identify your target application volume from Table 1. Note that the l/min outputs identified above relate to single sided sprayer output with application made to both sides of trees along rows, or completely around individual large trees.
[2] Acceptable travel speeds will be determined by the ability of the sprayer to project the spray plume into the centres and tops of the trees, as a rule of thumb speeds in trees over 5m tall should not exceed 3.5 km/hr.
[3] Pump output capacity will determine whether these target volumes can be achieved or not. Remember that 20% or more of pump output capacity is usually needed to maintain spray tank agitation.

unnecessary environmental agrichemical loading and this is recommended best practice wherever it is practical to do so.

The use of per hectare spray application terminology is to be discouraged as the same canopies on different row spacings need very different litre per hectare application rates but need exactly the same sprayer nozzling setup and outputs. Table 3 shows the litre per hectare application volumes that the distance based outputs given in Table 1 convert to for different sized trees on 7, 11 or 14 metre row spacings.

CONCLUSIONS

Dilute spray application volume requirements on different tree sizes can be defined using canopy volume estimates. The most practical and relevant system for setting up sprayers to deliver target application volumes to different trees is one in which the sprayer is calibrated to deliver a target output per 100 metres of travel. On the basis of the results from recent spray deposit testing work undertaken on New Zealand avocado canopies, an Australian system for distance based calibration has been adapted for use with New Zealand

Table 3. Spray application volume recommendations expressed in L/ha for open (coverage factor = 17) to dense (coverage factor = 11) avocado canopies on three different row spacings.

	Coverage factor (cubic metres of canopy volume covered per litre of dilute spray mix for open (lhs) to dense (rhs) canopies		
	17	**14**	**11**
Tree height and spread (m)	**Spray application volume ranges recommended (L/ha) for open to dense canopies on row spacing = 7.0m**		
3	800	900	1200
4	1300	1600	2100
5	2100	2600	3200
6	3000	3700	4700
Tree height and spread (m)	**Spray application volume ranges recommended (L/ha) for open to dense canopies on row spacing = 11.0m**		
3	500	600	700
4	900	1000	1300
5	1300	1600	2100
6	1900	2300	3000
7	2600	3200	4000
8 - 12 m	2600	3200	4000
Tree height and spread (m)	**Spray application volume ranges recommended (L/ha) for open to dense canopies on row spacing = 14.0m**		
3	400	500	600
4	700	800	1000
5	1100	1300	1600
6	1500	1800	2300
7	2100	2500	3200
8 - 12 m	2100	2500	3200

avocado canopies. Tables giving recommended spray delivery volumes per 100 metres of sprayed row have been prepared for different sized canopies, along with a table specifying the required litre per minute sprayer output volumes to deliver these target application volumes at different travel speeds.

ACKNOWLEDGEMENTS

The MAF Sustainable Farming Fund for support of this work through project 04/102 Tailoring pesticide application technology to avocado canopies http://www.maf.govt.nz/sff/about-projects/search/04-102/index.htm

REFERENCES

Furness, G.O. (2005). Orchard and vineyard spraying handbook for Australia and New Zealand. *SARDI.* 53pp.

Gaskin, R.E. and Manktelow, D.W. (2007). Adjuvant Prescriptions to Improve Spray Efficacy and Application Efficiency on NZ Avocados. *Avoscene October 2007.*

Gaskin, R.E. and Pathan, A.K. (2007). Characterising plant surfaces and adjuvant interactions to improve pesticide spray retention and coverage on avocados. *New Zealand Avocado Growers' Association Annual Research Report* Vol **6:** 63-70

Hickey, K.D. (1986). Methods for evaluating pesticides for the control of plant pathogens. *APS Press.* 312pp.

Manktelow, D.W.L. and Praat, J-P. (1997). The Tree-Row-Volume spraying system and its potential use in New Zealand. *Proceedings of the 50th N.Z. Plant Protection Society Conference. 119-124.*
http://ww.nzpps.org/journal/50/nzpp50_119.pdf

Manktelow, D.W.L. (1998). Factors affecting spray deposits and their biological affects on New Zealand apple canopies. *PhD thesis, Massey University, New Zealand.* 192pp.

Manktelow, D.W., Gurnsey, S.J. and MacGregor, A.M. (2004). Deposit variability and prediction in fruit crops: What use are label rates anyway? *Aspects of Applied Biology* **71***: International Advances in Pesticide Application.* 269-278 http://walnuts.org.nz/reports/depositvariability.pdf

Manktelow, D.W, May, B. and Gaskin, R.E. (2006). Spray application concepts and terminology. *Avoscene March 2006.*

Manktelow, D.W and Gaskin, R.E. (2006). Gains in spraying efficiency and effectiveness. *Avoscene September 2006.*